Programming with Blocks and Grand Central Dispatch

Session 406

These are confidential sessions—please refrain from streaming, blogging, or taking pictures.

Programming with Blocks and Grand Central Dispatch

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Wizard of Runtimes

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Blocks

```
(lambda (a) (add a d))
```

Scheme

LISP

SmallTalk

```
10 timesRepeat:[pen turn:d; draw]
```

Ruby

```
z.each {|val| puts(val + d.to_s) }
```

```
(lambda (a) (add a d))
```

Scheme

LISP

SmallTalk

```
10 timesRepeat:[pen turn:d; draw]
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Ruby

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z.each {|val| puts(val + d.to_s) }
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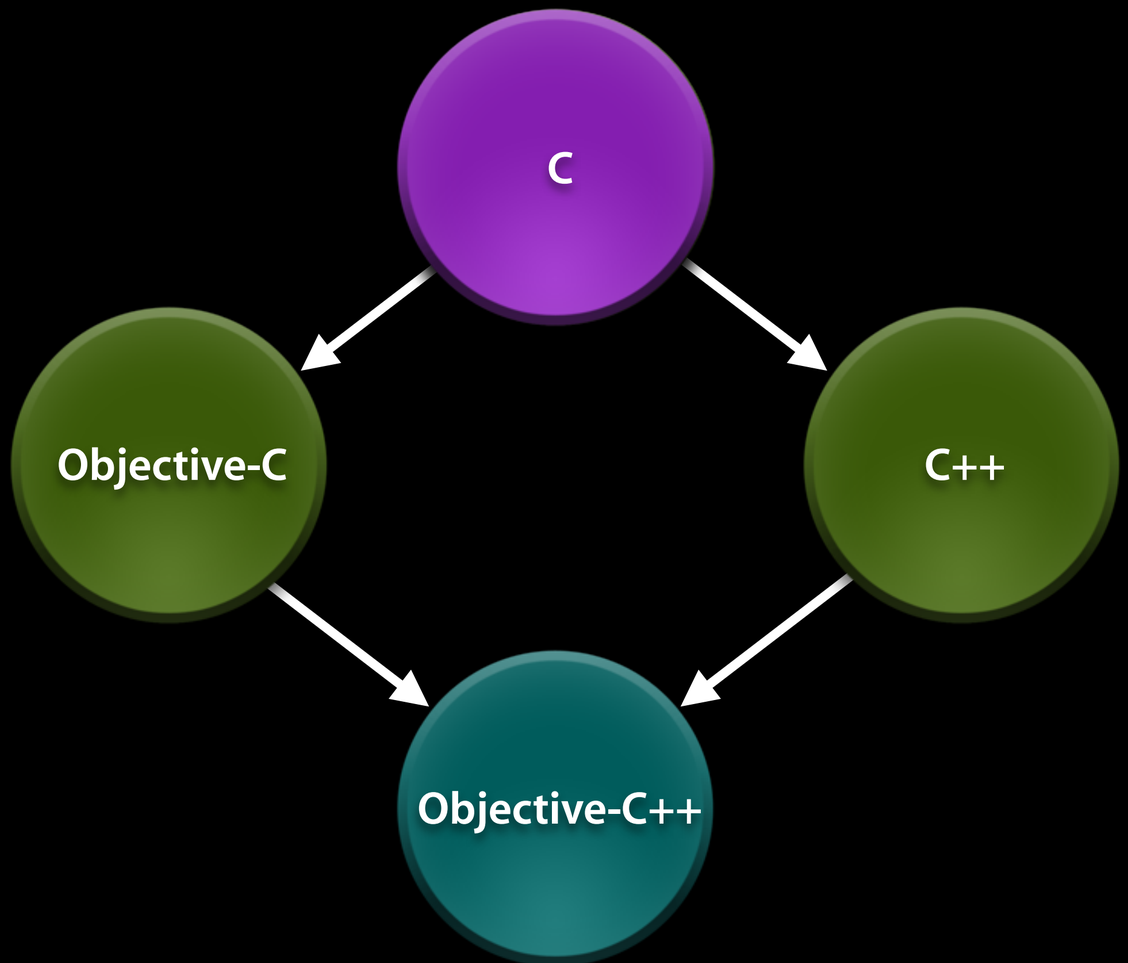
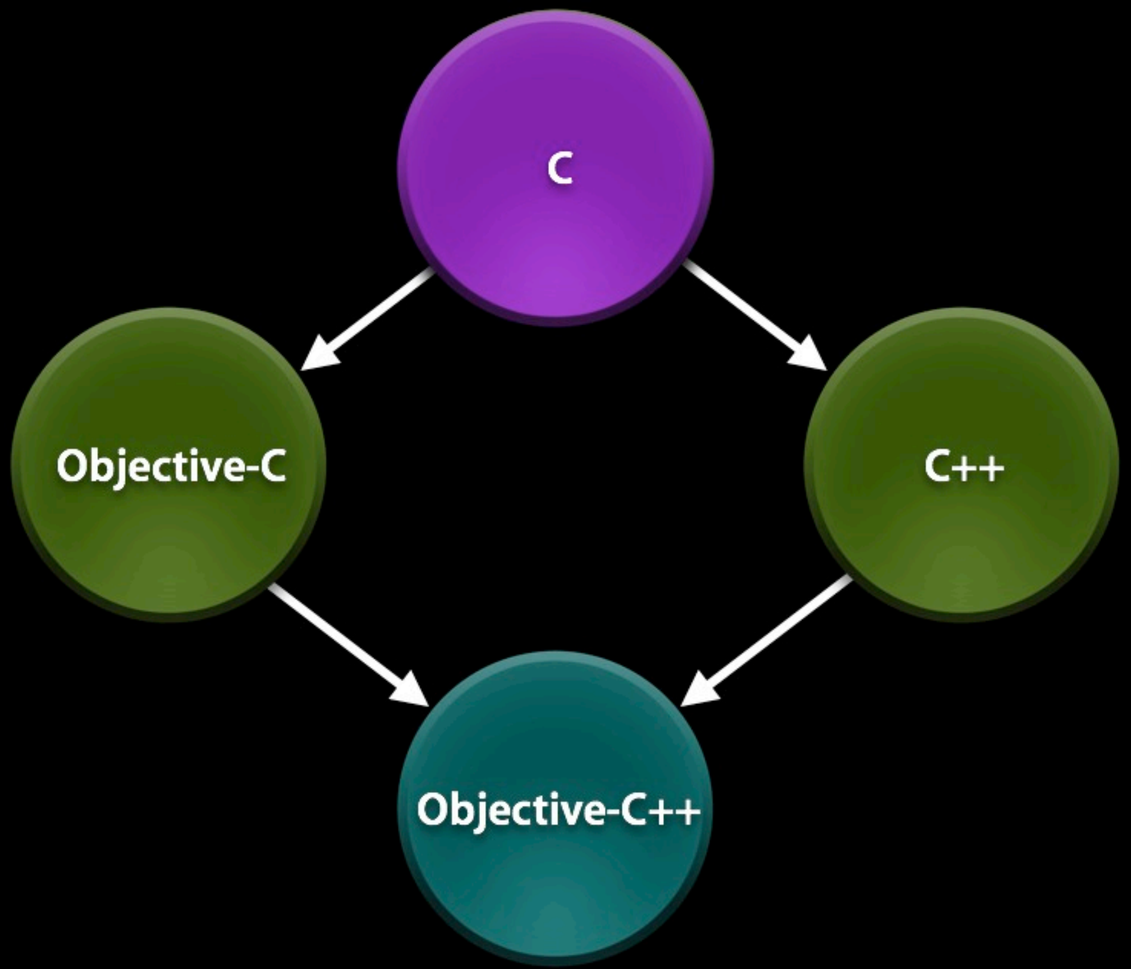

C
Objective-C
C++
Objective-C++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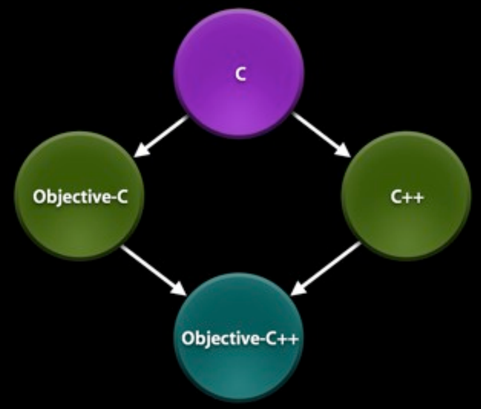



```
repeat(10, ^{ putc('0'+d); });
```

```
int d = i % 10;
repeat(10, ^{ putc('0'+d); });
```

A Block Reference Declaration

```
void (^block)(void);
```

Use Typedefs

```
typedef void (^workBlk_t)(void);
```

Do Block N Times Function

```
typedef void (^workBlk_t)(void);

void
repeat(int n, workBlk_t block) {
        for (int i = 0; i < n; ++i)
                block();
}
```

Traditional Uses for Closures…

Wrapper

```
typedef void (^vstr_t)(char *);
void AllLinesInFile(char *f, vstr_t block)
{
    FILE *fp = fopen(f, "r");
    if (!fp) return;
    char line[1024];
    while (fgets(line, 1024, fp))
        block(line);
    fclose(fp);
}
```

Wrapper

```
think;
think;
think;
AllLinesInFile(filename,  ^ (char *line) {
    compute;
    compute;
    compute;
}
```

Non-Wrapper Version

```
think;
think;
think;
FILE *fp = fopen(filename, "r");
if (fp) {
    char line[1024];
    while (fgets(line, 1024, fp)) {
        compute;
        compute;
        compute;
    }
    fclose(fp);
}
```

Wrapper

```
think;
think;
think;
AllLinesInFile(filename,  ^ (char *line) {
    compute;
    compute;
    compute;
}
```

Map

```
@implementation NSArray (WWDC)
- (NSArray *)map:(id (^)(id))xform {
    id result = [NSMutableArray array];
    for (id elem in self)
        [result addObject:xform(elem)];
    return result;
}
@end
```

Collect

```
@implementation NSArray (WWDC)
- (NSArray *)collect:(BOOL (^)(id))predicate {
    id result = [NSMutableArray array];
    for (id elem in self)
        if (predicate(elem))
            [result addObject:elem];
    return result;
}
@end
```

"Collect" in Use

```
id longLines = [allLines collect:
                        ^ BOOL (id item) {
        return [item length] > 20;
}];
```

New Uses

Traditional: qsort_r

```
void qsort_r (
        void *array,
        size_t nElems,
        size_t width,
        void *callback_argument,
        int (*compare)(void *l, void *r, void *cb)
);
```

Traditional: qsort_r

1. Declare custom structure type

```
typedef struct {
    int stringOption;
    BOOL ageFirst;
    ...;
} PeopleSort_t;
```

Traditional: qsort_r

2. Write compare function using custom structure

```
int myCustomCompare(void *p1, void *p2,
                    void *ctx) {
    ...
    if (((PeopleSort_t *)ctx)->ageFirst)
        ...
    ...
}
```

Traditional: qsort_r

3. Declare and initialize custom structure

```
void sortPeople(BOOL ageFirst) {
    int options = ...
    PeopleSort_t ctx = {
        ageFirst,
        options,
        ...};
```

Traditional: qsort_r

4. Call qsort_r

```
...
qsort_r(array, nelems, width,
                        &ctx, myCustomCompare);
```

New: qsort_b

```
void qsort_b (
        void *array,
        size_t nElems,
        size_t width,
        int (^compare)(void *l, void *r)
);
```

New: qsort_b

1. call qsort_b

```
void sortPeople(BOOL ageFirst) {
    int options = ...
qsort_b(array, nelems, width, ^ {
        ...
        if (ageFirst > 0)
            ...;
        ...
 });
```

Blocks are a Far Better Call Back API

- Old style
  - `qsort_r(..., void *ctx, cb_t func);`
  - `performSelector:withObject:`
  - `performSelector:withObject:withObject:`
  - `setTarget:, setAction: pair`
  - NSNotifications require userInfo dictionary to hold requisite data
- New style
  - `setCallback(^(param-list) { code });`
  - Language interoperable!

Lifetime

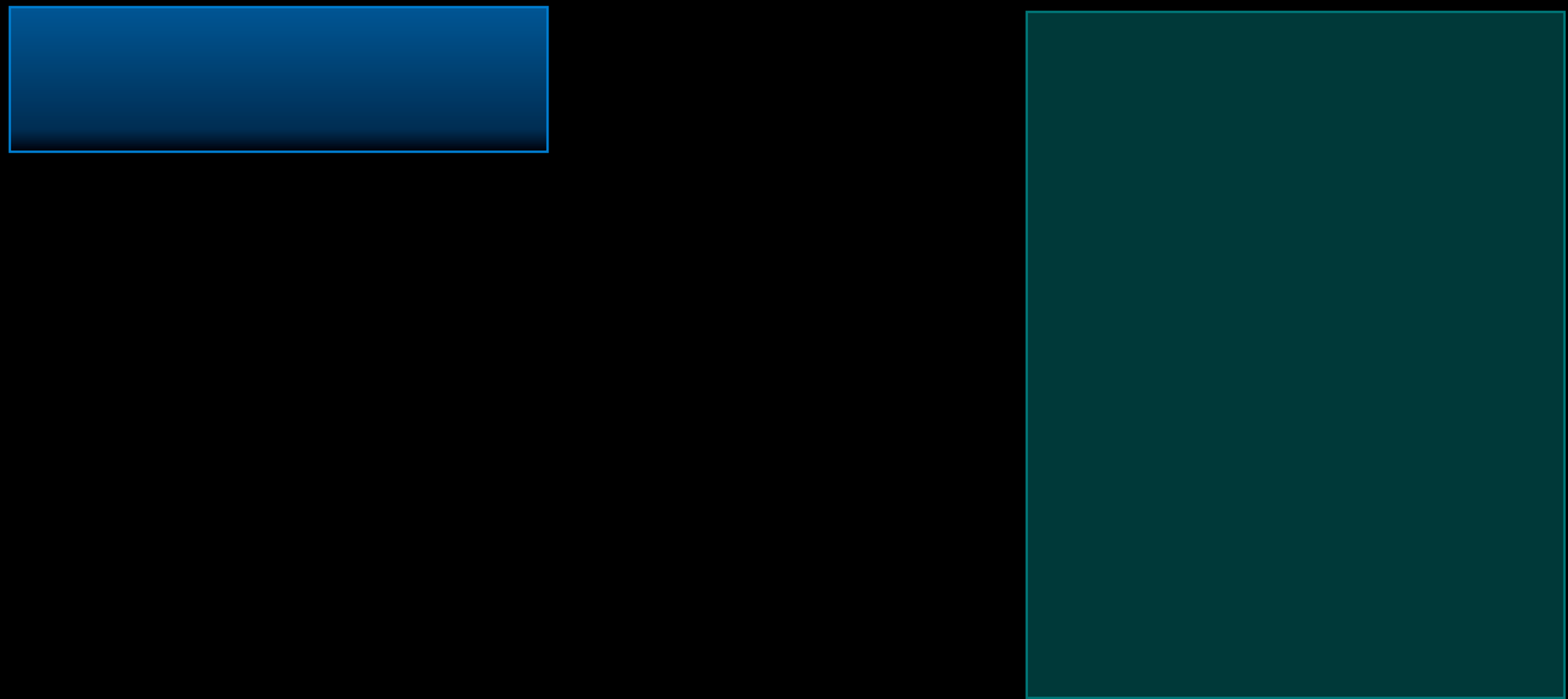
- Blocks start out on the stack
- Can be copied to the heap
- Blocks have private const copy of stack (auto) variables
- Mutable variables must be declared with a `__block` keyword
  - Shared with all other blocks that use that variable
  - Shared with the scope of declaration

New __block Storage Class

```
__block id result = nil;
[dict enumerateKeysAndObjectsUsingBlock:
      ^ (id key, id value, BOOL *stop) {
            if ([object isEqual:sought)]) {
                result = key;
                *stop = YES;
            }
        }];
```

Block Lifetime

Initial State Before Function Call



Stack

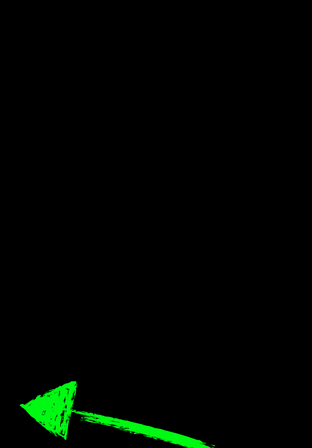
Heap

State Before Copy to Heap

```
int local;

__block int shared;

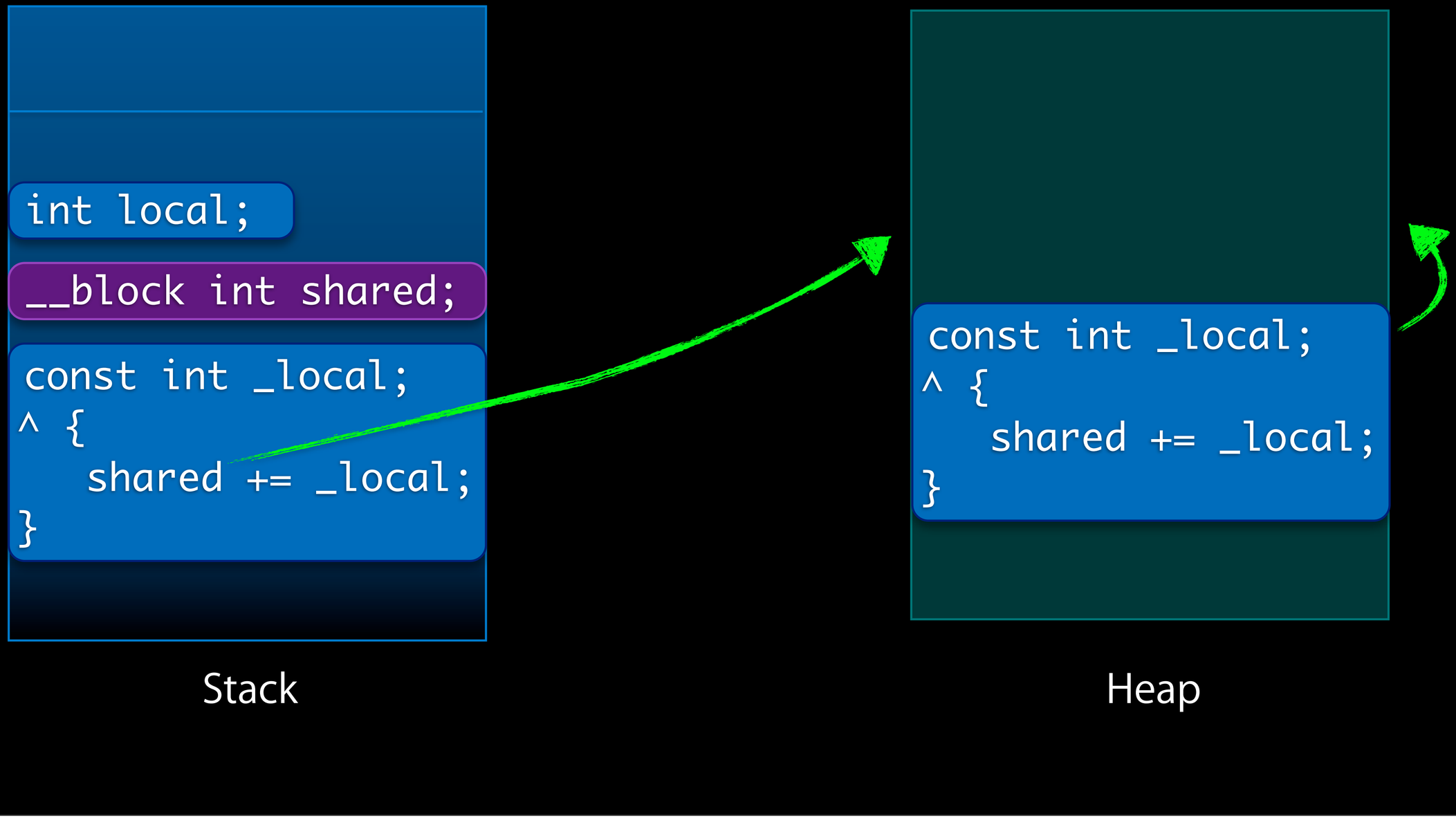
const int _local;
^ {
    shared += _local;
}
```



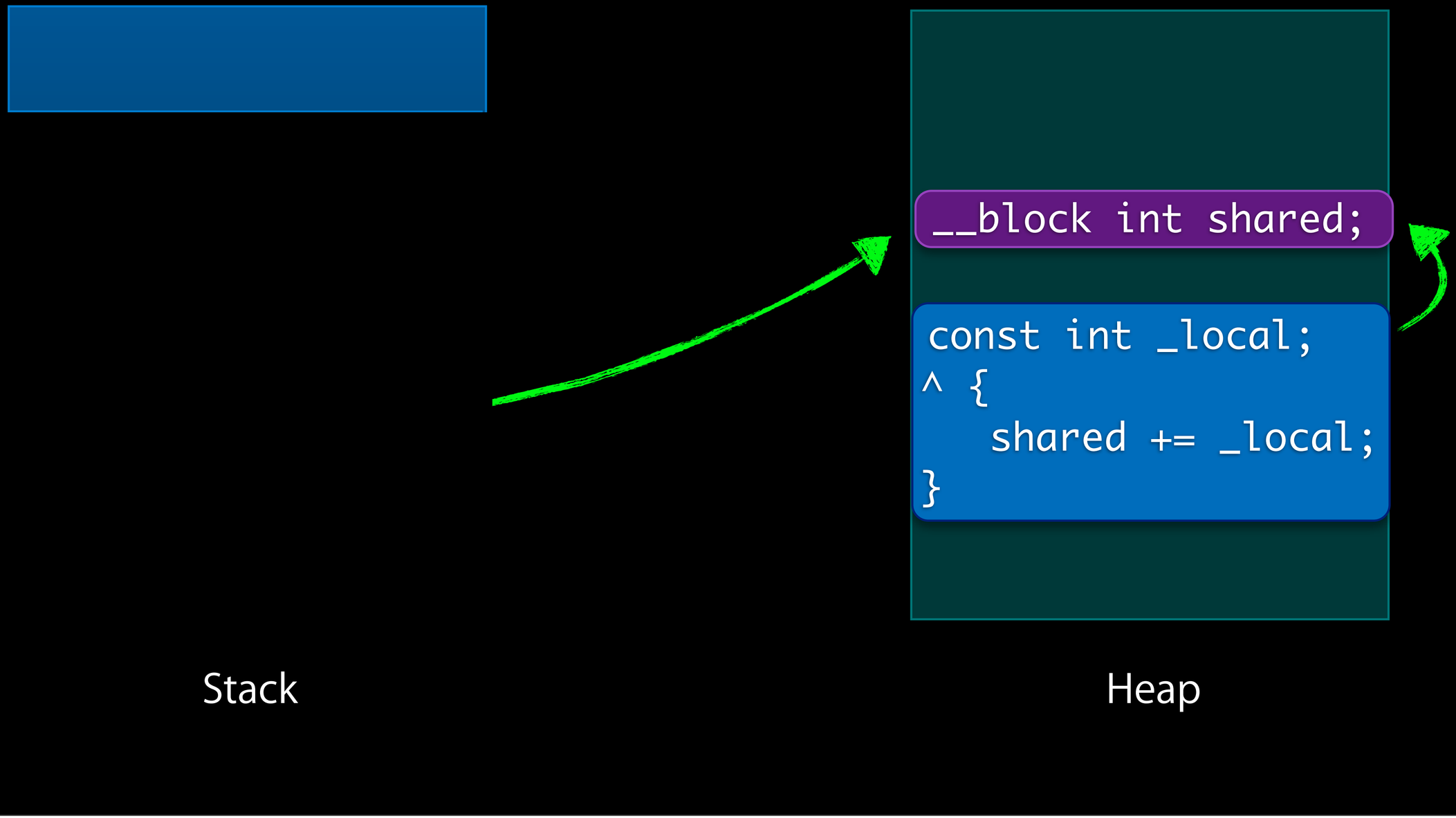
Stack

Heap

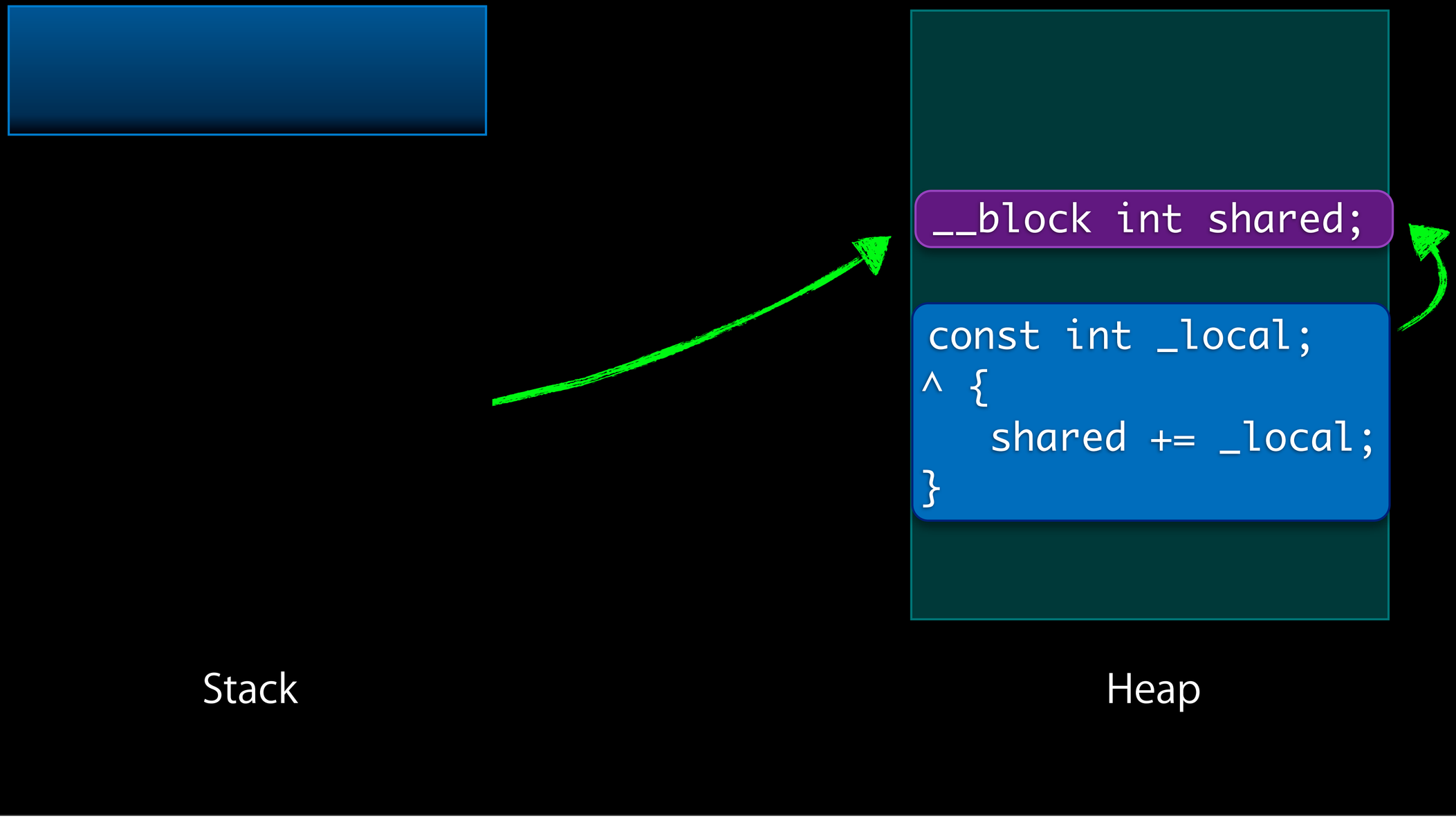
After Copy to Heap



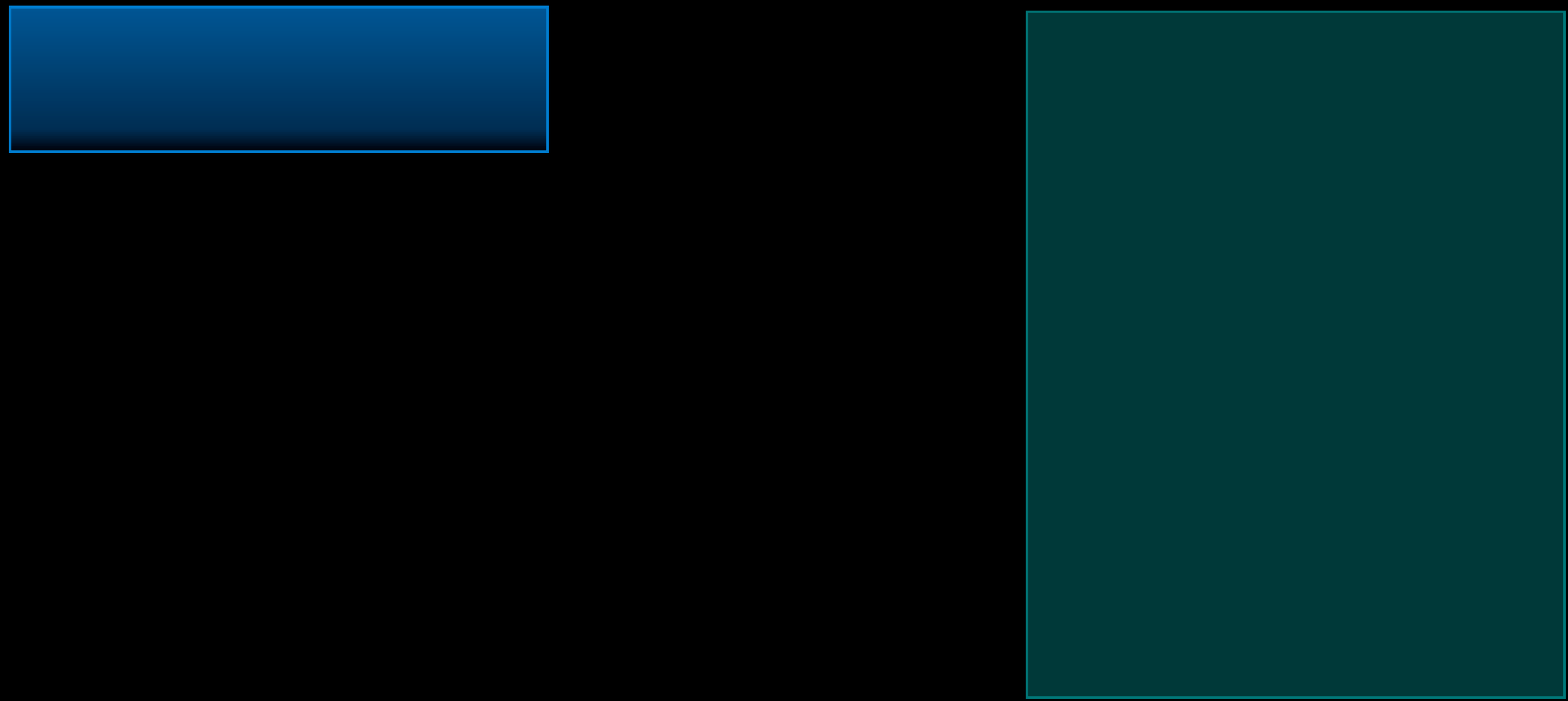
Case 1: Function Might Return…



Case 2: Heap Object Might Perish First



Leaving Us at Our Initial State



Stack

Heap

Objective-C Specializations

- All blocks are also always Objective-C objects!
  - Respond to the `-copy` (and `-release`) messages
  - `@property(copy) void (^graphicCallBack)(CGImage x);`

Objective-C and Garbage Collection Advancements	Russian Hill Wednesday 5:00PM

Summary: What are Blocks Good For?

- Over 100 Snow Leopard APIs use blocks!
- Traditional (blocking, single-threaded) uses
  - Collection iterations with or without options
  - Collection map, reduce, collect, …
  - Wrappers
- Call back replacements (various-threaded-nesses)
- Asynchronous (nonblocking, multithreaded) uses
  - Concurrent computation on independent data
  - Serialized computation on shared data
  - All combos of the above

GCD

GCD?

Asynchronous Blocks

```
dispatch_async(queue, ^{
    printf(“Hello\n”);
});
```

16 Virtual Cores

2 Cores

100% Multicore

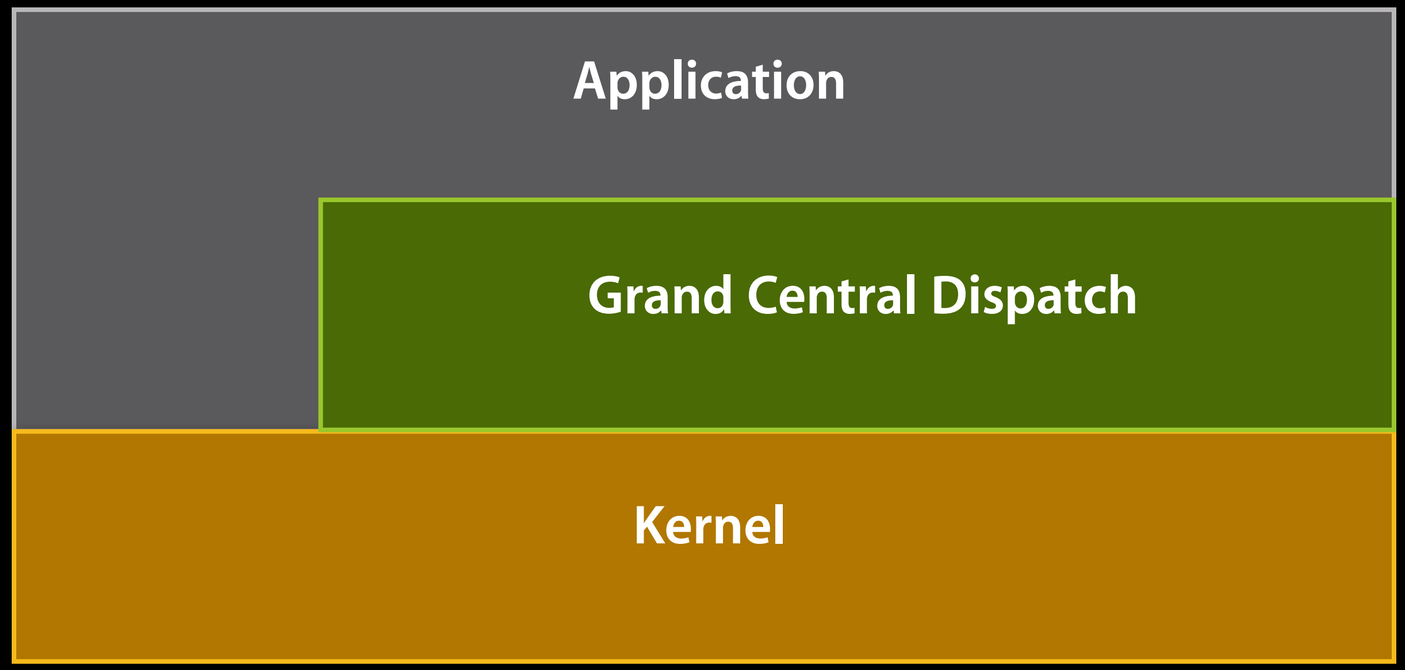
One More Problem

User experience

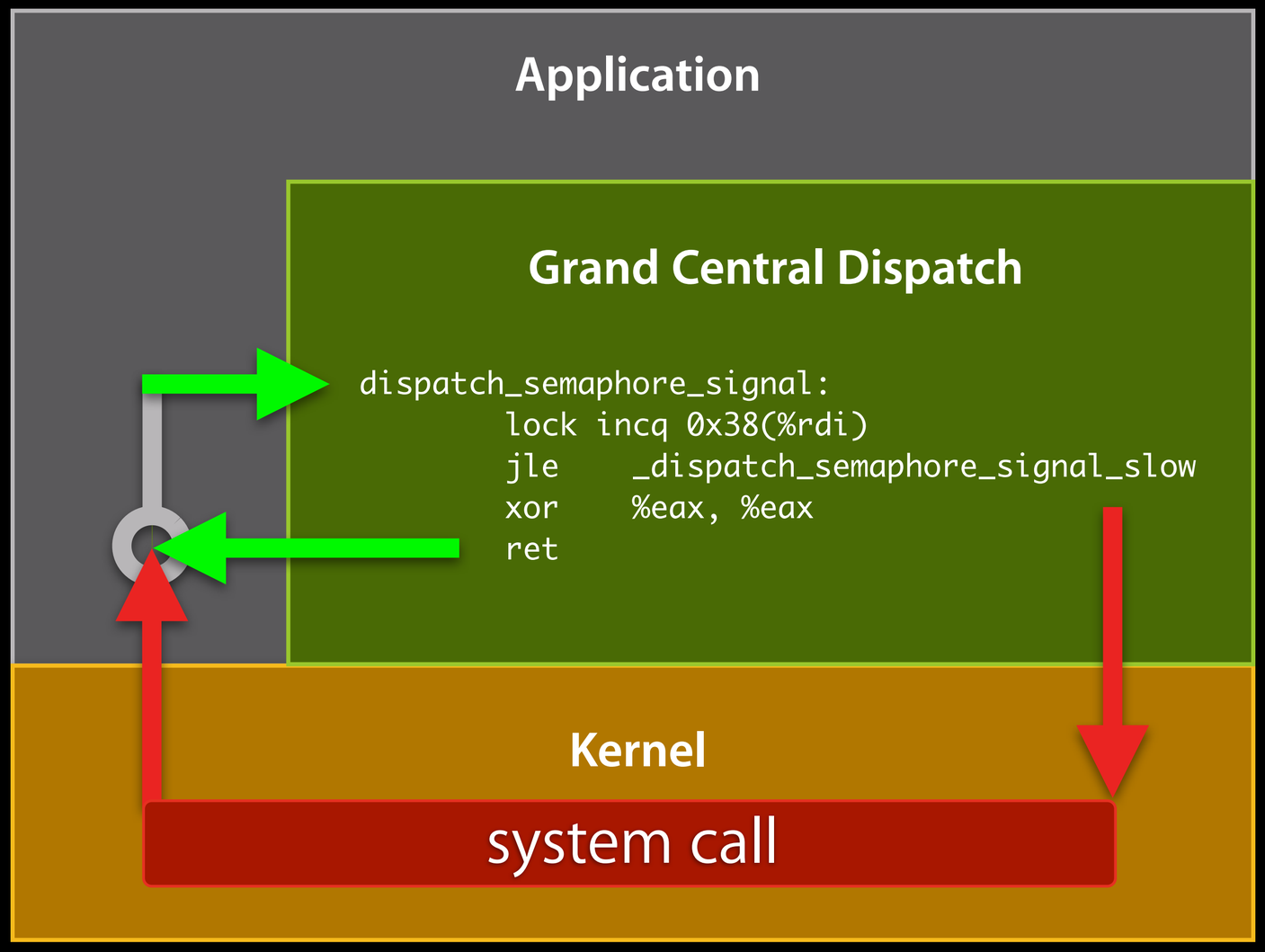
GCD?

Fast ***Easy*** ***Fun***

Technology Stack



Kernel Bypass



200x

Dispatch semaphore versus pthread condition variables under contention on a 2.26GHz 16-way Mac Pro

Fast ***Easy*** ***Fun***

Better Metaphor

Blocks and Queues

```
dispatch_async(queue, ^{
    printf(“Hello\n”);
});
```

Fast ***Easy*** ***Fun***

Stories on Campus

“Wow, my subsystem runs a lot faster!”

“Why hasn’t it always been this way?”

“Dispatch is like writing poetry.”

Technology

Overview

Technology Overview

- GCD is part of libSystem.dylib
- Available to all applications
  - `#include <dispatch/dispatch.h>`

Queues
dispatch_queue_t

dispatch_queue_create
dispatch_queue_get_label
dispatch_get_main_queue
dispatch_get_global_queue
dispatch_get_current_queue
dispatch_main
dispatch_apply
dispatch_apply_f
dispatch_async
dispatch_async_f
dispatch_sync
dispatch_sync_f
dispatch_after
dispatch_after_f

Semaphores
dispatch_semaphore_t

dispatch_semaphore_create
dispatch_semaphore_signal
dispatch_semaphore_wait

Objects
dispatch_object_t

dispatch_retain
dispatch_release
dispatch_suspend
dispatch_resume
dispatch_debug
dispatch_get_context
dispatch_set_context
dispatch_set_finalizer_f
dispatch_set_target_queue

Groups
dispatch_group_t

dispatch_group_create
dispatch_group_enter
dispatch_group_leave
dispatch_group_wait
dispatch_group_notify
dispatch_group_notify_f
dispatch_group_async
dispatch_group_async_f

Sources
dispatch_source_t

dispatch_source_create
dispatch_source_cancel
dispatch_source_testcancel
dispatch_source_merge_data
dispatch_source_get_handle
dispatch_source_get_mask
dispatch_source_get_data
dispatch_source_set_timer
dispatch_source_set_event_handler
dispatch_source_set_event_handler_f
dispatch_source_set_cancel_handler
dispatch_source_set_cancel_handler_f

Not Objects

Time
dispatch_time_t

dispatch_time
dispatch_walltime

Once
dispatch_once_t

dispatch_once
dispatch_once_f

Queues

dispatch_queue_t

dispatch_queue_create
dispatch_queue_get_label
dispatch_get_main_queue
dispatch_get_global_queue
dispatch_get_current_queue
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dispatch_apply_f
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dispatch_after_f

Objects

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Semaphores

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Groups

dispatch_group_t

dispatch_group_create
dispatch_group_enter
dispatch_group_leave
dispatch_group_wait
dispatch_group_notify
dispatch_group_notify_f
dispatch_group_async
dispatch_group_async_f

Not Objects

Time

dispatch_time_t

dispatch_time
dispatch_walltime

Once

dispatch_once_t

dispatch_once
dispatch_once_f

Related Sessions

Understanding Grand Central Dispatch in Depth	Presidio Thursday 9:00AM
Migrating Your Application to Grand Central Dispatch	Pacific Heights Thursday 2:00PM
Designing Your Cocoa Application for Concurrency	Nob Hill Tuesday 3:30PM
What's New in Instruments	Pacific Heights Wednesday 3:30PM
Objective-C and Garbage Collection Advancements	Russian Hill Wednesday 5:00PM
Advanced Debugging and Performance Analysis	Nob Hill Thursday 9:00AM

GCD Objects

GCD Objects

- Some polymorphic API
- Reference counted memory management
  - `dispatch_retain(object);`
  - `dispatch_release(object);`

- GCD does the right thing
  - Retains parameters when needed

- A few other shared functions

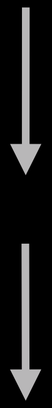
Queues

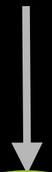
Queues

- Lightweight list of blocks
- Asynchronous execution
- Enqueue/dequeue is FIFO

Your Thread

A = ^{ ... };





Dispatch Queue

Automatic Thread

Queues

```
dispatch_async(queue, ^{ /* A */ });

dispatch_async(queue, ^{ /* B */ });

dispatch_async(queue, ^{ /* C */ });
```

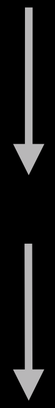
Global Queues

Global Queues

- Lightweight list of blocks
- Asynchronous execution
- Enqueue/dequeue is FIFO
- Concurrent execution

Your Thread

A = ^{ ... };



Global Dispatch Queue

Automatic Thread

Automatic Thread

Queue of Blocks

```
queue = dispatch_get_global_queue(0, 0);

dispatch_async(queue, ^{ /* A */ });

dispatch_async(queue, ^{ /* B */ });

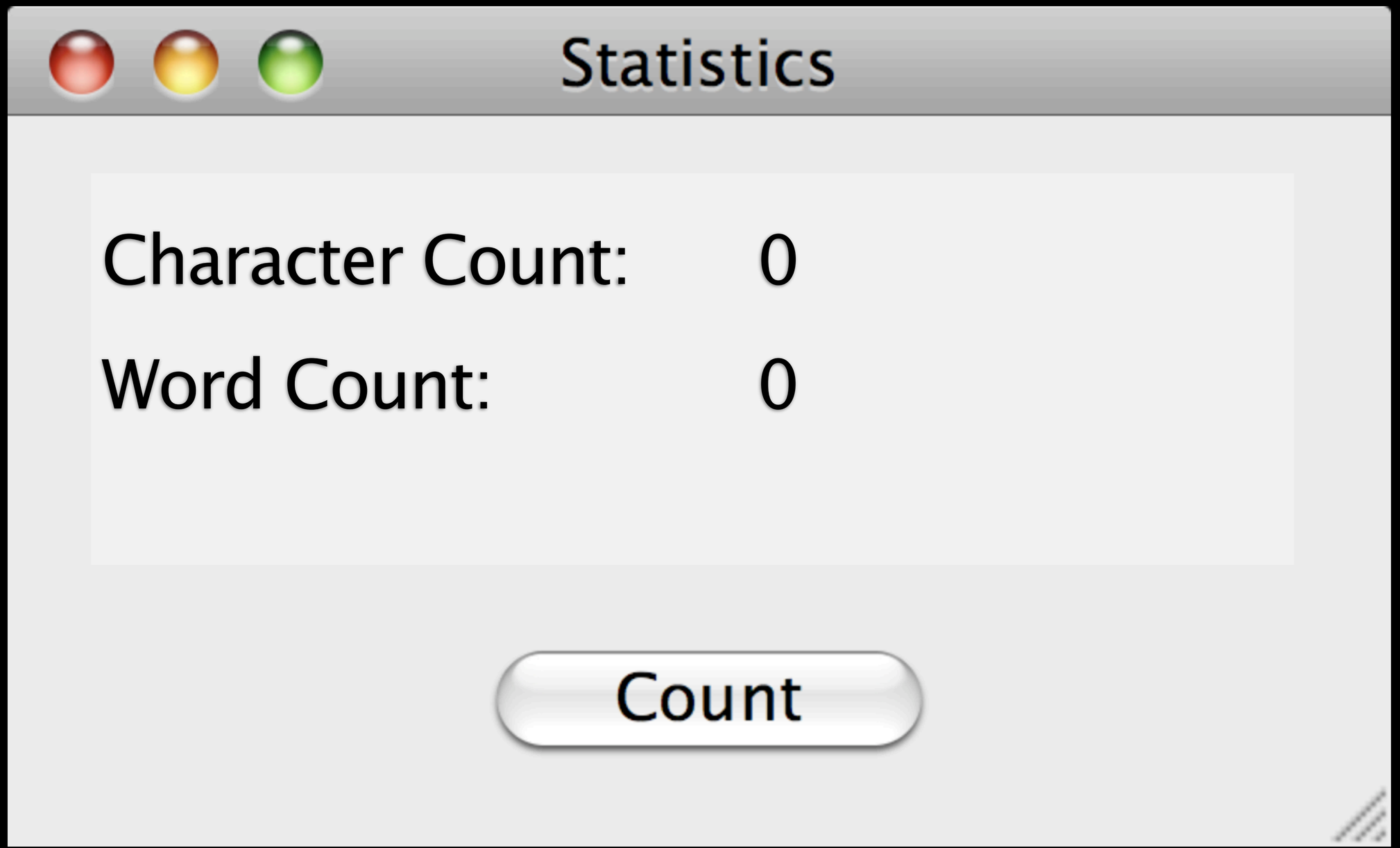
dispatch_async(queue, ^{ /* C */ });
```

Easy Concurrency

Suppose you wanted to count the characters, words, and paragraphs in a document.

And suppose that your document is large,

very large…

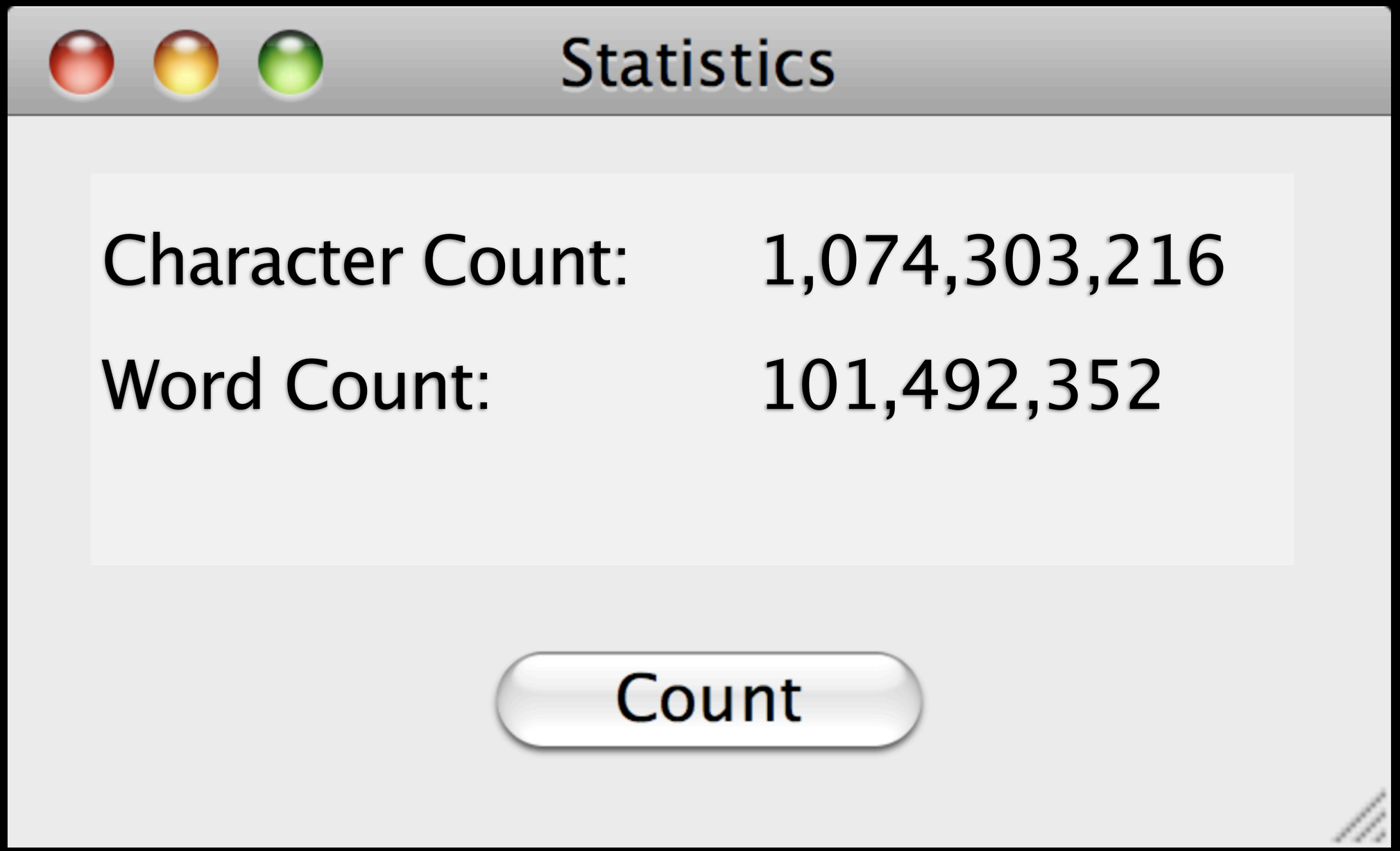

Statistics
Character Count: 0
Word Count: 0
Count

Statistics

Character Count: 0

Word Count: 0

Count


Statistics
Character Count: 1,074,303,216
Word Count: 101,492,352
Count

```
for (i = 0; i < count; i++) {
    results[idx] = do_scan(text, idx);
}

total = summarize(results, count);
```

```
                                {
        results[idx] = do_scan(text, idx);
    }

    total = summarize(results, count);
```

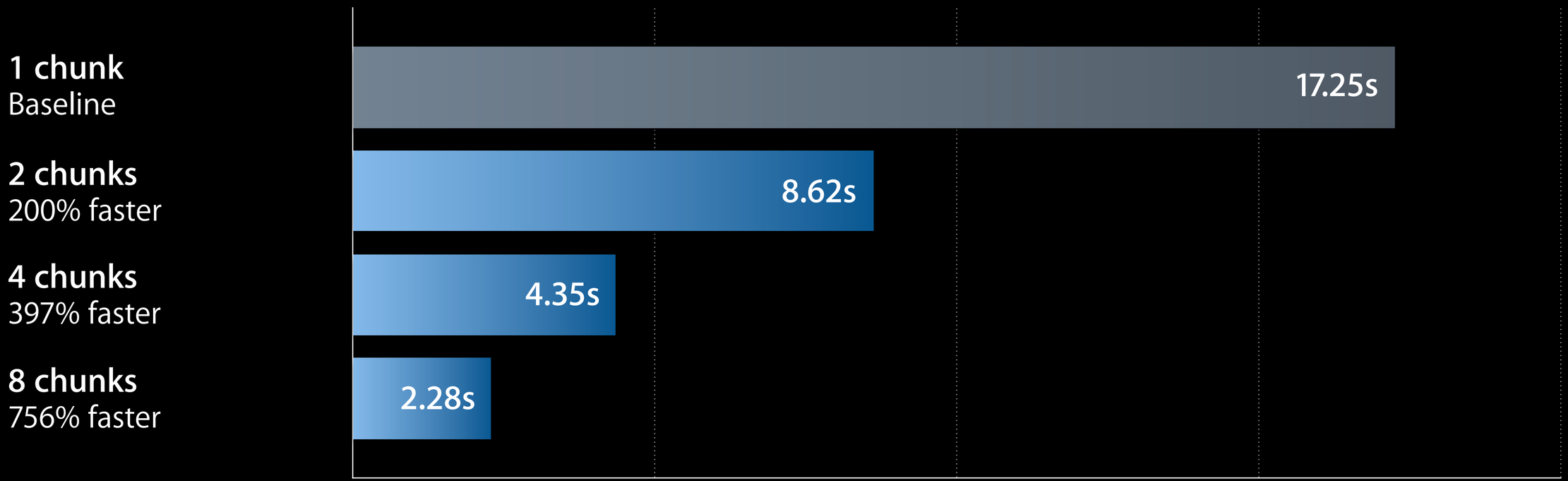
```
queue = dispatch_get_global_queue(0, 0);

dispatch_apply(count, queue, ^(size_t idx) {
    results[idx] = do_scan(text, idx);
});

total = summarize(results, count);
```

dispatch_apply() Elapsed Time

Smaller bars are better



Elapsed time processing an approx. 1GB text file on an 8 core Mac Pro

Asynchronous Design

Asynchronous Design

```
- (IBAction)compute:(NSButton *)sender
{
    NSDictionary *dict = [myDoc summarize];
    [myModel setDict:dict];
    [myView setNeedsDisplay:YES];
    [dict release];
}
```

Asynchronous Design

```
- (IBAction)compute:(NSButton *)sender
{
    dispatch_async(dispatch_get_global_queue(0, 0), ^{
        NSDictionary *dict = [myDoc summarize];
        dispatch_async(dispatch_get_main_queue(), ^{
            [myModel setDict:dict];
            [myView setNeedsDisplay:YES];
            [dict release];
        });
    });
}
```

Main Queue

Dispatch Main Queue

- Executes blocks serially on main thread

- Cooperates with the Cocoa main run loop
  - NSApplicationMain()

- Usable by pure GCD programs
  - dispatch_main()

Main Queue

```
int main(int argc, char **argv)
{
    dispatch_queue_t queue = dispatch_get_main_queue();

    dispatch_async(queue, ^{
        printf(“%s: Hello World\n”, argv[0]);
    });

    // Application and library initialization
    // All may use the main queue

    NSApplicationMain(argc, argv);      // Cocoa apps
    // dispatch_main();                 // Pure GCD apps
}
```

Serial Queues

Serial Queues

- Lightweight list of blocks
- Asynchronous execution
- Enqueue/dequeue is FIFO
- Serial completion

Your Thread

B = ^{ ... };

Another Thread

C = ^{ ... };

Dispatch Queue

Automatic Thread

Serial Queues

// Thread One	// Thread Two
dispatch_async(queue, ^{ /* A */ });	

dispatch_async(queue, ^{
    /* B */
});
	dispatch_async(queue, ^{
	    /* C */
	});

Serial Queues

```
queue = dispatch_queue_create(“com.example.purpose”, NULL);
```

```
label = dispatch_queue_get_label(queue);
```

```
printf(“Queue %p: %s\n”, queue, label);
```

Multiple Serial Queues

Multiple Serial Queues

- Queues are lightweight
- No imposed limits
- Natural to assign one queue per task
- Potential for inter-task concurrency

Your Thread

E = ^{ ... };

Dispatch Queue

Dispatch Queue

Automatic Thread

Multiple Serial Queues

```
q1 = dispatch_queue_create(“com.example.task1”, NULL);
q2 = dispatch_queue_create(“com.example.task2”, NULL);

dispatch_async(q1, ^{ /* A */ });

dispatch_async(q2, ^{ /* B */ });

dispatch_async(q1, ^{ /* C */ });

dispatch_async(q2, ^{ /* D */ });

dispatch_async(q1, ^{ /* E */ });
```

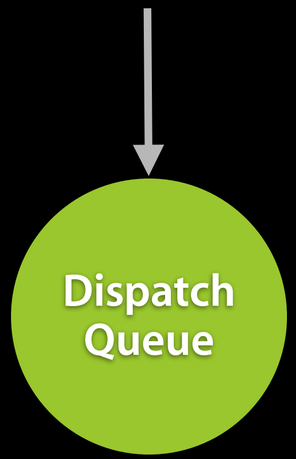
Grouping Multiple Blocks

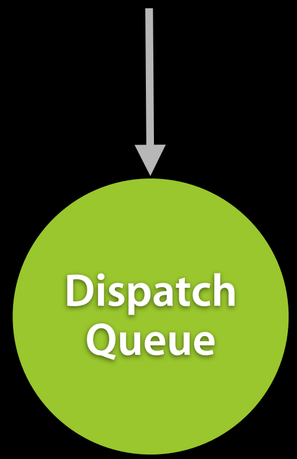
Grouping Blocks

- Track multiple blocks as a group
  - Empty group notification
- Blocks may run on different queues
- Blocks may add more blocks to the group
  - “Recursive decomposition”

Your Thread

E = ^{ ... };





Automatic Thread

Grouping Blocks

```
dispatch_group_t group = dispatch_group_create();
```

```
for (i = 0; i < count; i++) {
    dispatch_group_async(group, tasks[i]->queue, ^{
        do_something(tasks[i]);
    });
}
```

```
dispatch_group_notify(group, dispatch_get_main_queue(), ^{
    do_something_else(data);
});
```

```
dispatch_release(group);
```

Completion

- Groups are a generic completion notification system
- Nested blocks are the simple case
  - Fewer lines of code
  - More efficient

Completion

Nested blocks

```
dispatch_async(dispatch_get_global_queue(0, 0), ^{
    result_t rval = do_something();
    dispatch_async(dispatch_get_main_queue(), ^{
        result_draw(rval);
        result_free(rval);
    });
});
```

Completion

- What if asynchronous notifications are not practical?
- Code must then wait

Waiting

Waiting

- Bridging synchronous and asynchronous code
- Waiting for blocks to complete
  - Fork/join model
- Wait for one block
  - dispatch_sync()
- Groups are a generic solution

Waiting

```
__block result_t rval;

dispatch_sync(task->queue, ^{
    rval = do_something(task);
});

// use rval
```

Waiting

```
dispatch_group_t group = dispatch_group_create();
__block result_t rvals[count];
```

```
for (i = 0; i < count; i++) {
    dispatch_group_async(group, tasks[i]->queue, ^{
        rvals[i] = do_something(tasks[i]);
    });
}
```

```
dispatch_group_wait(group, DISPATCH_TIME_FOREVER);
dispatch_release(group);
```

```
// use rvals[]
```

DISPATCH_TIME_FOREVER ?

Time

Time

- Opaque type
  - Not safe for arithmetic
  - Not safe for comparisons
- Two well-known constants
  - DISPATCH_TIME_NOW
  - DISPATCH_TIME_FOREVER

Time

```
// wait forever (this always returns success)
dispatch_group_wait(group, DISPATCH_TIME_FOREVER);
```

```
// poll the group
if (dispatch_group_wait(group, DISPATCH_TIME_NOW)) {
    printf(“Group is not empty\n”);
}
```

Time

- Arbitrary timeouts are supported
- Also possible to defer block execution
  - dispatch_after()

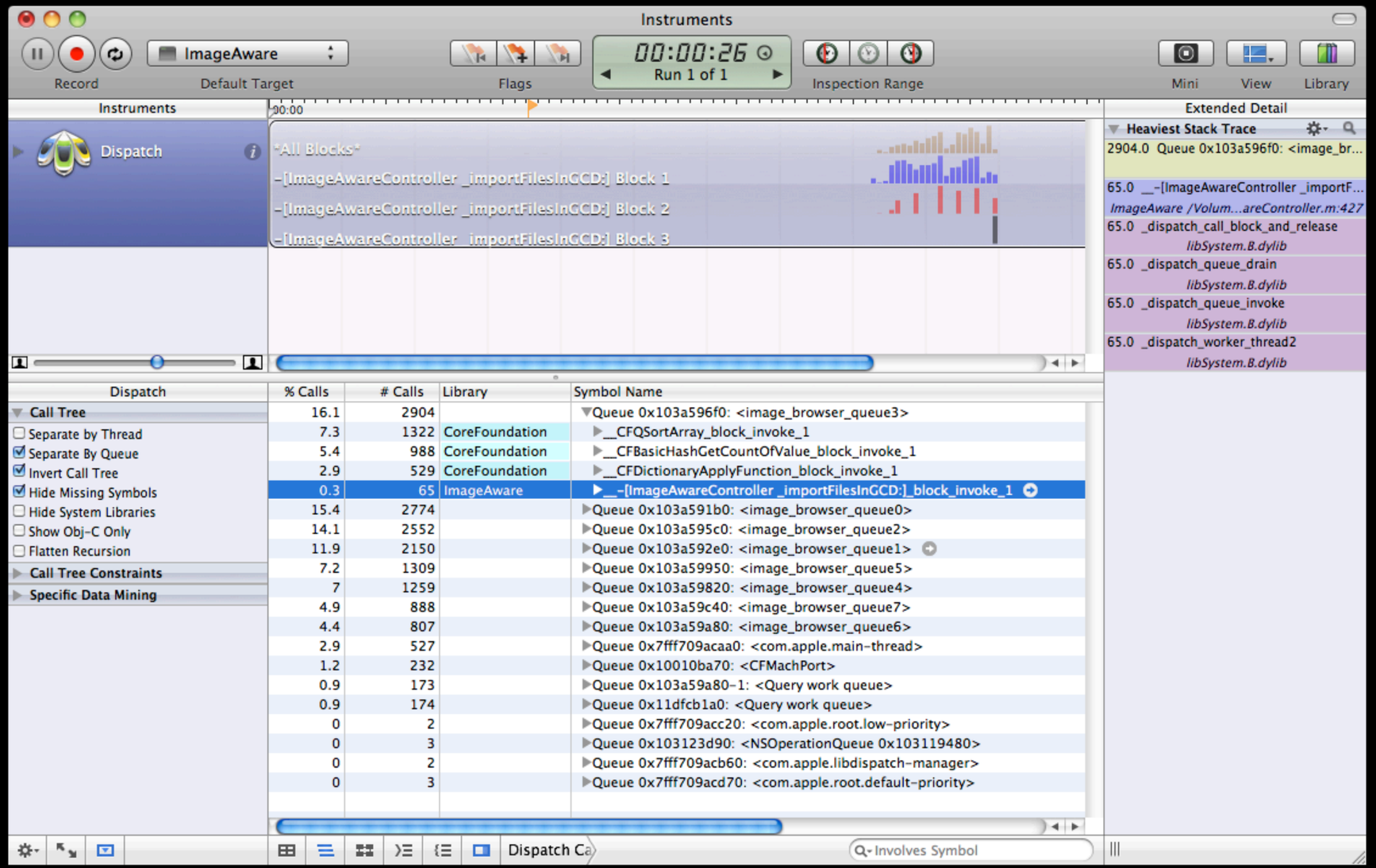
Understanding Grand Central Dispatch in Depth	Presidio Thursday 9:00AM

Instruments

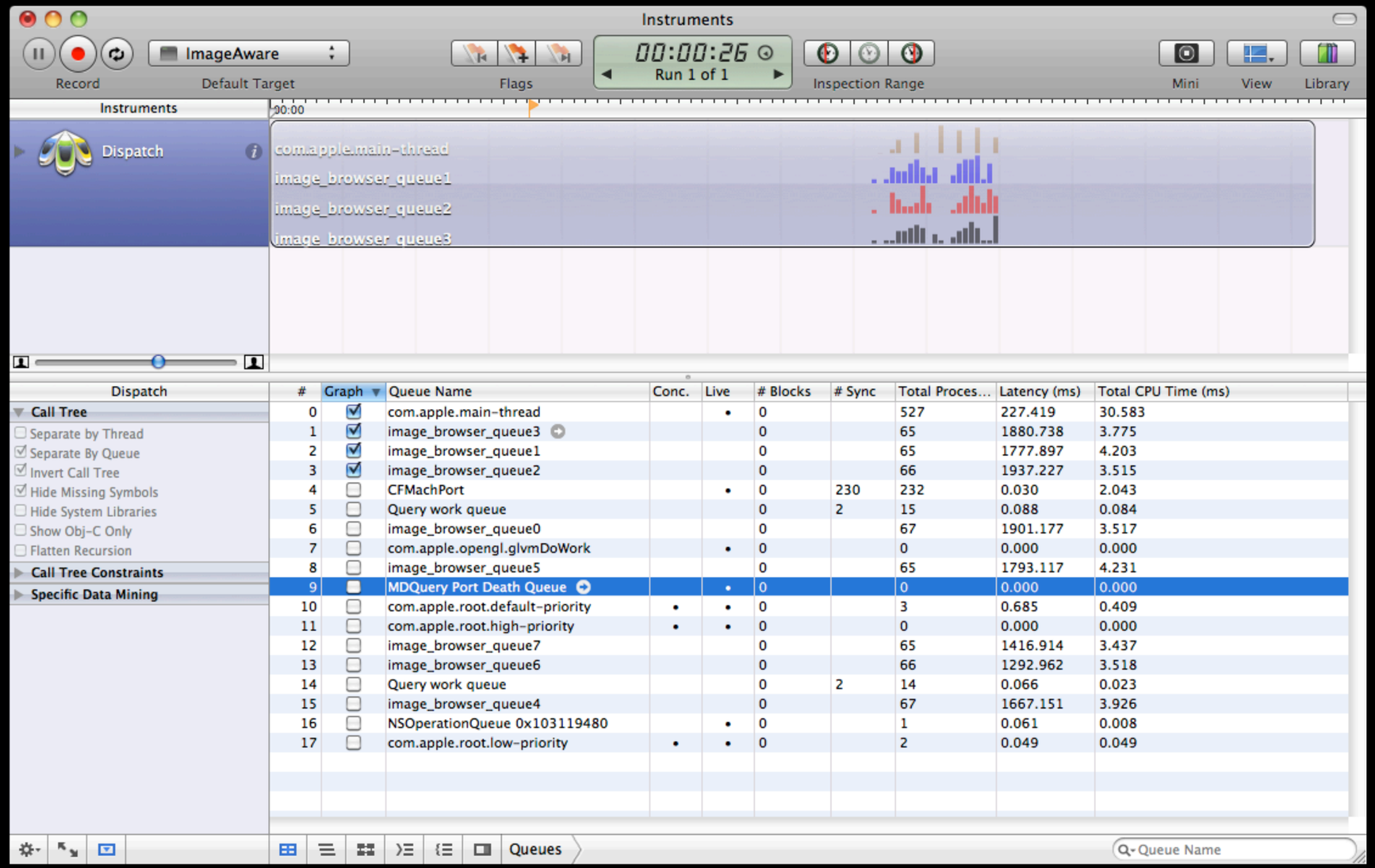
Instruments

- Behavior
  - Latency
  - Track which blocks are enqueued on which queues
  - Which blocks are executed synchronously
- Optimization
  - Longest executing blocks
  - Most executing blocks

Call Tree View

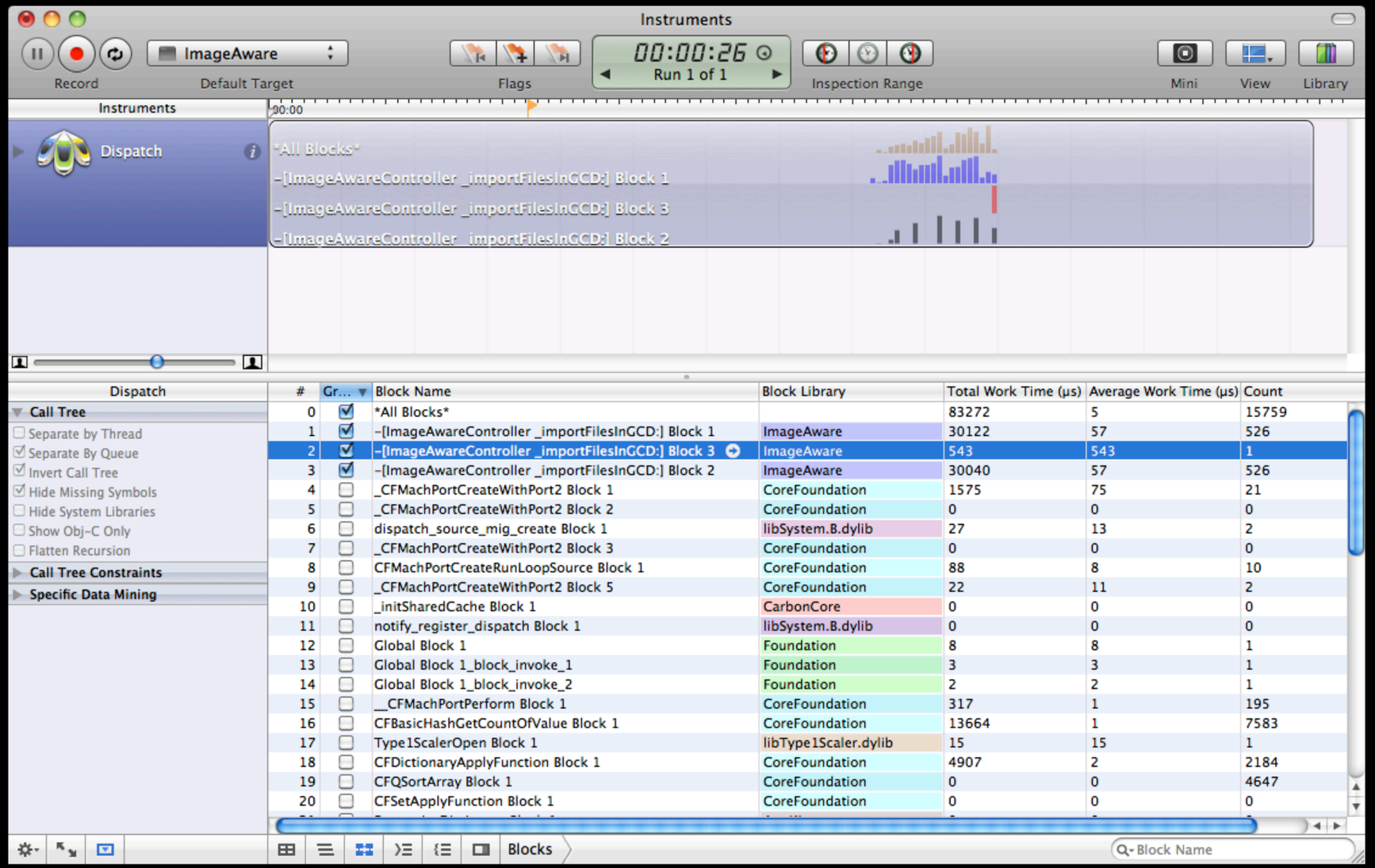


Queue View



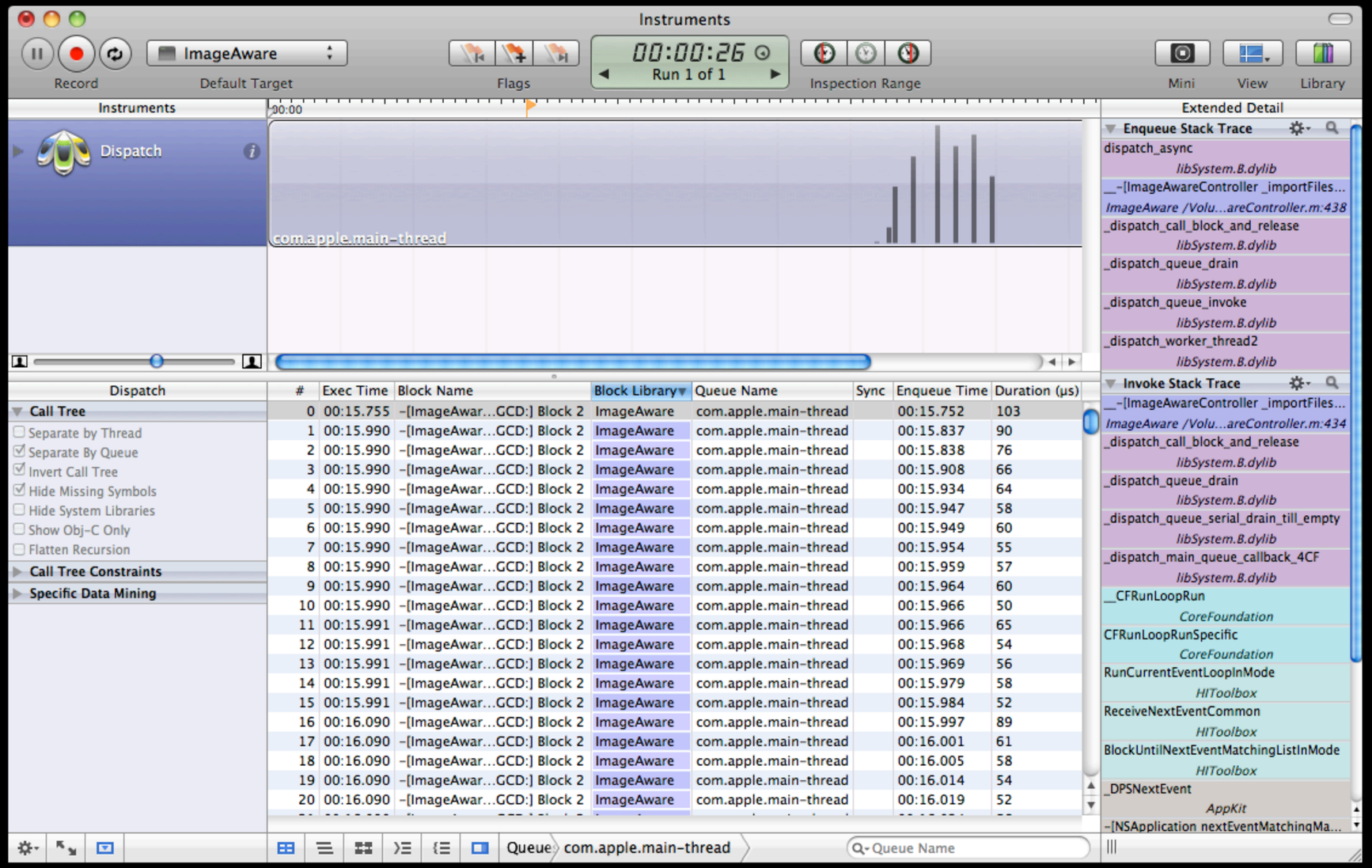
#	Graph	Queue Name	Conc.	Live	# Blocks	# Sync	Total Proces...	Latency (ms)	Total CPU Time (ms)
0	☑	com.apple.main-thread		•	0		527	227.419	30.583
1	☑	image_browser_queue3			0		65	1880.738	3.775
2	☑	image_browser_queue1			0		65	1777.897	4.203
3	☑	image_browser_queue2			0		66	1937.227	3.515
4	☐	CFMachPort		•	0	230	232	0.030	2.043
5	☐	Query work queue			0	2	15	0.088	0.084
6	☐	image_browser_queue0			0		67	1901.177	3.517
7	☐	com.apple.opengl.glvmDoWork		•	0		0	0.000	0.000
8	☐	image_browser_queue5			0		65	1793.117	4.231
9	☐	MDQuery Port Death Queue		•	0		0	0.000	0.000
10	☐	com.apple.root.default-priority	•	•	0		3	0.685	0.409
11	☐	com.apple.root.high-priority	•	•	0		0	0.000	0.000
12	☐	image_browser_queue7			0		65	1416.914	3.437
13	☐	image_browser_queue6			0		66	1292.962	3.518
14	☐	Query work queue			0	2	14	0.066	0.023
15	☐	image_browser_queue4			0		67	1667.151	3.926
16	☐	NSOperationQueue 0x103119480		•	0		1	0.061	0.008
17	☐	com.apple.root.low-priority	•	•	0		2	0.049	0.049

Block View



#	Gr...	Block Name	Block Library	Total Work Time (µs)	Average Work Time (µs)	Count
0	☑	*All Blocks*		83272	5	15759
1	☑	-[ImageAwareController _importFilesInGCD:] Block 1	ImageAware	30122	57	526
2	☑	-[ImageAwareController _importFilesInGCD:] Block 3	ImageAware	543	543	1
3	☑	-[ImageAwareController _importFilesInGCD:] Block 2	ImageAware	30040	57	526
4	☐	_CFMachPortCreateWithPort2 Block 1	CoreFoundation	1575	75	21
5	☐	_CFMachPortCreateWithPort2 Block 2	CoreFoundation	0	0	0
6	☐	dispatch_source_mig_create Block 1	libSystem.B.dylib	27	13	2
7	☐	_CFMachPortCreateWithPort2 Block 3	CoreFoundation	0	0	0
8	☐	CFMachPortCreateRunLoopSource Block 1	CoreFoundation	88	8	10
9	☐	_CFMachPortCreateWithPort2 Block 5	CoreFoundation	22	11	2
10	☐	_initSharedCache Block 1	CarbonCore	0	0	0
11	☐	notify_register_dispatch Block 1	libSystem.B.dylib	0	0	0
12	☐	Global Block 1	Foundation	8	8	1
13	☐	Global Block 1_block_invoke_1	Foundation	3	3	1
14	☐	Global Block 1_block_invoke_2	Foundation	2	2	1
15	☐	__CFMachPortPerform Block 1	CoreFoundation	317	1	195
16	☐	CFBasicHashGetCountOfValue Block 1	CoreFoundation	13664	1	7583
17	☐	Type1ScalerOpen Block 1	libType1Scaler.dylib	15	15	1
18	☐	CFDictionaryApplyFunction Block 1	CoreFoundation	4907	2	2184
19	☐	CFQSortArray Block 1	CoreFoundation	0	0	4647
20	☐	CFSetApplyFunction Block 1	CoreFoundation	0	0	0

Blocks Focus View



Instruments

What's New in Instruments	Pacific Heights Wednesday 3:30PM
Advanced Debugging and Performance Analysis	Nob Hill Thursday 9:00AM

GCD

Fast

Easy

Fun

More Information

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Developer Forums
> Mac Development > Grand Central Dispatch
http://devforums.apple.com/community/mac/gcd

Documentation
Concurrency Programming Guide
http://developer.apple.com/

Related Sessions

Understanding Grand Central Dispatch in Depth	Presidio Thursday 9:00AM
Migrating Your Application to Grand Central Dispatch	Pacific Heights Thursday 2:00PM
Designing Your Cocoa Application for Concurrency	Nob Hill Tuesday 3:30PM
What's New in Instruments	Pacific Heights Wednesday 3:30PM
Objective-C and Garbage Collection Advancements	Russian Hill Wednesday 5:00PM
Advanced Debugging and Performance Analysis	Nob Hill Thursday 9:00AM

Labs

Grand Central Dispatch Lab	Snow Leopard Lab Wednesday 3:30PM
Grand Central Dispatch Lab	Snow Leopard Lab Thursday 3:30PM

Q&A

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